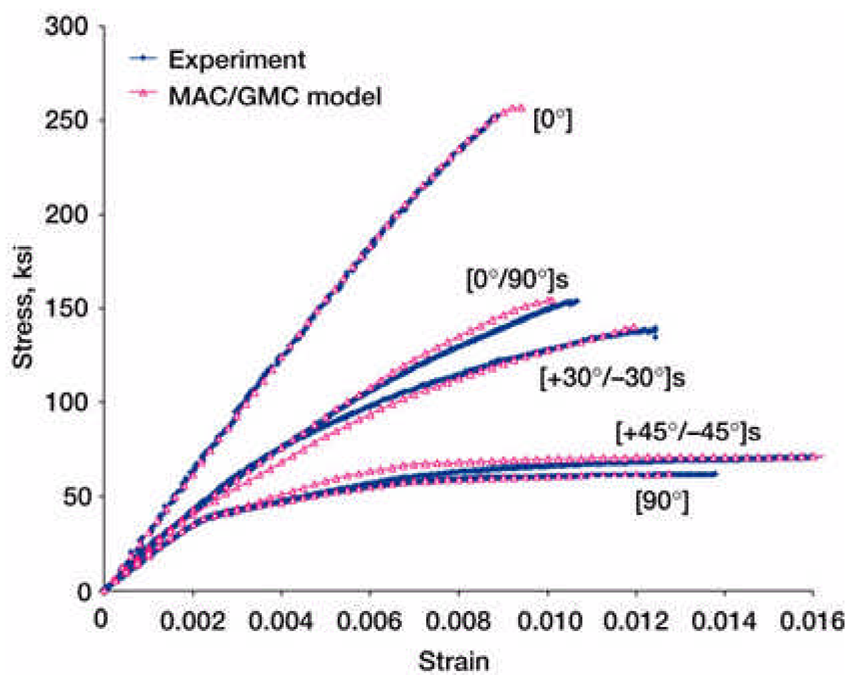
Deformation, Failure, and Fatigue Life of SiC/Ti-15-3 Laminates Accurately Predicted by MAC/GMC

NASA Glenn Research Center's Micromechanics Analysis Code with Generalized Method of Cells (MAC/GMC) (ref.1) has been extended to enable fully coupled macro-micro deformation, failure, and fatigue life predictions for advanced metal matrix, ceramic matrix, and polymer matrix composites. Because of the multiaxial nature of the code's underlying micromechanics model, GMC (ref. 2)--which allows the incorporation of complex local inelastic constitutive models--MAC/GMC finds its most important application in metal matrix composites, like the SiC/Ti-15-3 composite examined here. Furthermore, since GMC predicts the microscale fields within each constituent of the composite material, submodels for local effects such as fiber breakage, interfacial debonding, and matrix fatigue damage can and have been built into MAC/GMC. The present application of MAC/GMC highlights the combination of these features, which has enabled the accurate modeling of the deformation, failure, and life of titanium matrix composites (ref.3).

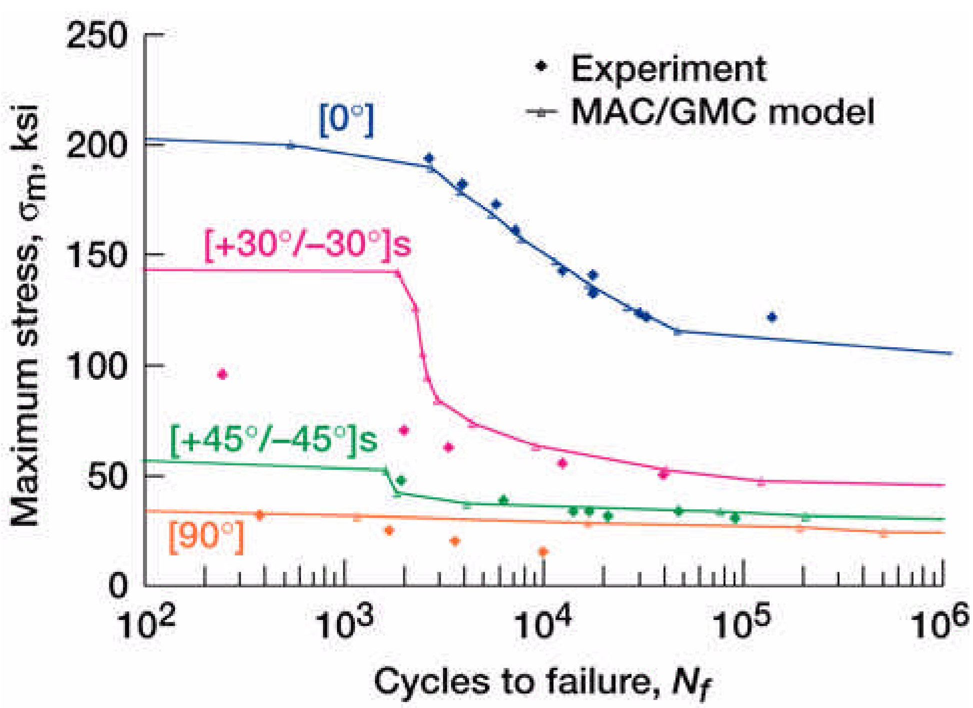


Deformation and failure of SiC/Ti-15-3 at room temperature.

Long description Tensile stress-strain curves for the following SiC/Ti-15-3 laminates (in order of how the curves lie on the plot, starting with the highest (i.e., stiffest and strongest)): 0°, 0°/90° symmetric, ±30° symmetric, ±45° symmetric, and 90°. The horizontal strain axis is unitless and progresses from 0 to 0.016. The vertical stress axis begins at 0 and ranges to 275 ksi. Room-temperature experimental curves, as well as curves predicted using MAC/GMC, are shown. The curves show excellent agreement between the experiment and the model, not only for the deformation, but also for the stress at failure (ultimate tensile strength, UTS). The approximate UTS values for the five laminates are 255, 155, 145, 70, and 60 ksi.

The preceding graph compares the room-temperature deformation and static life predicted by MAC/GMC with experimental data for five SiC/Ti-15-3 laminates (ref. 4). In these simulations, the Ti-15-3 matrix inelastic behavior is modeled using incremental plasticity theory (ref. 5) with piecewise linear postyield response. The SiC fiber failure behavior is modeled using Curtin's effective fiber-breakage model (ref. 6). The normal and shear fiber-matrix interfacial debonding, which allows the "knee" present in the [90°] and [±30°]s laminate[1]curves to be captured, is simulated with the evolving compliant interface model (ref. 7). The result of the coupling of these microscale models is the excellent macroscale agreement evident in the preceding graph.

The following graph compares the elevated-temperature low-cycle fatigue (LCF) response of the SiC/Ti-15-3 laminates predicted by MAC/GMC with experimental data (ref.8). Here, a fatigue damage model (ref. 9) was included for the matrix and the fiber (ref. 10). Again, the coupled nature of the microscale failure, debonding, and fatigue models within MAC/GMC has led to good agreement for this complex simulation.



Stress-controlled LCF of 35-vol% SiC/Ti-15-3 at 800°F.

Long description Experimental and predicted load versus cycles-to-failure curves (S-N curves) for the following 0.35-vol%-fraction SiC/Ti-15-3 laminates (in order of how the curves lie on the plot, starting with the highest (i.e., greatest stress for a given number of cycles)): 0°, ±30° symmetric, ±45° symmetric, and 90°. Both the predicted and the experimental curves qualitatively exhibit the “backward s” shape typical of S-N curves.

The horizontal cycles-to-failure axis ranges from one hundred to one million on a log scale. The vertical maximum stress axis ranges from 0 to 250 ksi on a linear scale. Agreement between the experiment and the MAC/GMC results are excellent for the 0° and ±45° laminates. For the ±30° laminate, agreement is good in the higher cycle range (above 10,000), but in the lower cycle range, the prediction is above the experimental curve (that is, for a given number of cycles to failure, the stress is too high). On the contrary, for the 90° laminate, the predicted curve matches the experiment in the lower cycle range, but is too high in the higher cycle range.

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[1]The letter "s" after the closing bracket indicates "symmetric."